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Measurements of pressure disturbances on the ground due to Sonic Bangs

by

M.O.W. Wolfe
and
H.C. Woolley

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SUMMARY

The pressure disturbances on the ground due to Sonic Bangs from diving aircraft have been measured on several occasions, as opportunities arose. The measurements were made with a sensitive instrument capable of indicating the pressure time event accurately for small pressures and high rates of change of pressure.

It was not possible to control the experiments adequately and the results are therefore random in character. Sufficient information was obtained to substantiate a theory due to Warren[1]. The average amplitude of the pressure wave was shown to be 0.7 lb/sq. ft and the greatest incremental pressure measured was 1.56 lb/sq. ft.

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1 Introduction

An understanding of the Sonic Bang is important because of its objectionable character and the possibility of damage to property. Up to the present, sonic bangs have been made by aircraft when diving from high altitude at high speed, so that the time during which the aircraft speed exceeds that of sound is necessarily short. The effects have not been as great, therefore, as they would be if the aircraft flew continuously at supersonic speed in level flight at low altitude. There is a possibility, therefore, that sonic bangs may become more serious in the future.

The experiments described here were undertaken for two purposes: first to provide data from which theories could be checked, and secondly to determine the magnitude of the disturbance. At the time the observations were begun no quantitative measurements were available. It was known, however, from the reports of witnesses, that the disturbances covered a wide area on the ground and that one, two and sometimes three bangs were heard, depending on the locations of the observers in relation to the flight path of the aeroplane.

Pressure-time measurements of sonic bangs were made with several types of sensitive fluctuating pressure pick-ups at Lasham aerodrome and at the R.A.E. Similar experiments were made at Larkhill Range with Rocket Missiles. For the experiments at Lasham an observer on the ground was in radio communication with the pilot during the dives, and the aircraft were flown on a prearranged flight path. The experiments at the R.A.E. were made during the 1953 S.B.A.C. Show when coordination was not possible between the pilot of the aircraft and the ground observer. The results of these observations, therefore, are random and can only be expected to give some statistical information on the magnitude of the pressure peaks.

From a consideration of the results of the experiments with aircraft it seemed that the sonic bang was primarily an aerodynamic effect, a convenient qualitative analysis of the phenomenon being given by Warren[1]. Although quantitative estimates of the pressure based on Warren's work were in fair agreement with measured pressures, the coordination of the ground measurements with the aircraft flight plan was never good enough to enable the theory to be fully substantiated. Since the disturbances covered a wide area on the ground, moreover, and the measurements were made at only one point, it was not known whether the measurements were made at the centre of the disturbance. Pressures greater than those observed might therefore have occurred at other points. For these reasons Rocket Missile experiments were planned and carried out at Larkhill range. Using rockets in conjunction with Radio Doppler and Cine theodolite equipment it was possible to measure the velocity-time history and the track of the missile accurately. It was also possible by observing whether or not sonic bangs were made by missiles in free flight, to check another theory, known as the acoustic theory, which attributes the phenomenon to the noise made by aircraft engines. In these experiments simultaneous recordings at three positions on the ground were made.

From the experiments at Lasham the shape of the pressure-time pulse on the ground was established and, where more than one bang was recorded during a dive, the average interval of time between successive pressure peaks was found to be 0.125 seconds. The average peak pressure was 0.7 lb per square foot, and the greatest pressure peak recorded was 1.56 lb per square foot. The time interval between successive bangs and the shape of the wave were in accord with the aerodynamic theory; the quantitative effect forecast by the theory was also in fair agreement with the measured pressures.

Only the peak pressures of four disturbances were measured during the R.A.E. experiments. These pressures were respectively 0.09, 0.15, 0.24 and 0.18 lb per square foot.

In the experiments at Larkhill disturbances were observed and recorded on two occasions from sighter rockets. In each case two bangs were observed. The average peak pressure was 0.3 lb per square foot and the greatest pressure recorded was 0.36 lb per square foot and the average time interval between successive peaks was 0.56 seconds. The general characteristics and shape of the pressure waves were the same as for the aircraft. Since it was possible to establish that the bangs received on the ground were produced after cessation of the rocket motor the acoustic theory was discredited.

2 Instrumentation

In the early experiments several types of pressure pick-up were tried, with varying degrees of success. These included a moving coil microphone, a piezo electric pressure pick-up, and a sensitive condenser type microphone. The requirements were severe, since exceptionally low pressures combined with high rates of change of pressure were involved. A very sensitive pick-up capable also of responding accurately to very high frequencies was therefore required. These conditions are difficult to satisfy in a single pick-up since a sensitive instrument must have a very flexible movement, which implies a low natural frequency and consequently a poor response to high frequencies. The technique which was finally adopted, and which proved to be satisfactory, was the use of a specially designed miniature condenser type pick-up of poor sensitivity but high natural frequency in conjunction with an electronic amplifier of high gain and a cathode ray tube recorder. With this arrangement the poor sensitivity of the pick-up was offset by the high gain of the amplifier, and since the natural frequency of the pick-up was 17,000 c.p.s. an adequate high frequency response was achieved.

The pick-up used in the experiments was a modified form of that described in reference 2. A stiffer diaphragm was used to improve the high frequency response. Photographs of the pick-up are shown in Figs.1 and 2. The amplifying and recording equipment consisted of a frequency modulated pre-amplifying stage followed by a demodulator, a high gain DC amplifier and a cathode ray tube photographic recorder. Timing signals generated by a 100 c.p.s. tuning fork controlled oscillator were photographed on the record. The equipment is described in detail in reference 3, and is shown in Fig.3.

3 Experiments at Lasham Aerodrome

The experiments at Lasham Aerodrome were made on Sabre service aircraft. The pilots were briefed to climb to 42,000 ft and then dive at approximately 75 degrees to the horizontal, aiming the aircraft at the point on the ground at which the pressure observations were being made. The approximate flight path of the aircraft is shown in Fig.4. The time of entry to the dive, the Mach number at intervals during the dive and the time of commencement of pull out were communicated by radio to the ground observer by the pilot. The results of these experiments are given in the following tabulation for six disturbances:-

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Disturbance Number	1st Pressure		2nd Pressure			3rd Pressure		
	Peak Pressure lb/sq. ft	Duration secs	Time after 1st peak secs	Peak Pressure lb/sq. ft	Duration secs	Time after 2nd peak secs	Peak Pressure lb/sq. ft	Duration secs
1	1.04	0.02	0.125	0.52	0.02	0.03	0.31	0.01
2	0.78	0.02	0.12	0.42	0.01	0.13	0.42	0.01
3	0.78	0.02	0.12	0.73	0.02	0.13	0.26	0.01
4	0.37	0.02	NONE	-	-	NONE	-	-
5	0.37	0.01	0.15	1.56	0.02	NONE	-	-
6	NOTHING RECORDED							

An example of the pressure time curve for a typical triple bang disturbance is shown in Fig.5.

4 Experiments at the R.A.E.

Pressure observations were made during the 1953 S.B.A.C. Show at the R.A.E. In this case no coordination was possible between the pilot of the aircraft and the ground observer. In view of this it was decided to limit the observations to simple measurements of the peak positive pressures of the bangs, measuring only the first bang when more than one bang occurred. Owing to the lack of adequate coordination several of the bangs that occurred during the Show went unrecorded. However, the peak pressures of the four disturbances that were recorded are thought to be reasonably representative. They were made by Hawker Hunter and Supermarine Swift aircraft.

The results are given in the following tabulation:-

Disturbance Number	Peak Pressure lb/sq. ft
1	0.09
2	0.15
3	0.24
4	0.18

5 Rocket Experiments at Larkhill Range

The rocket experiments at Larkhill Range were undertaken primarily because of the difficulty of coordinating the flight plan of an aircraft with the ground observations.

The range was equipped with Radio Doppler and Cine Theodolite equipment, by means of which it was possible to obtain an accurate indication of the velocity time history of the missile and its trajectory. By this means it was hoped that the points on the trajectory at which the component of the missile velocity in the direction of the observer became sonic could be accurately related in space and time to the pressure disturbances on the ground.

The missiles employed were sighter rounds. These are simple rockets without boosters, used mainly for the purpose of checking the range measurement apparatus. The absence of a booster was advantageous, because the noise of the explosion at booster separation would have increased the difficulty of identifying the true sonic bangs on the recorded traces.

A typical velocity time curve for a sighter round is shown in Fig.6, and a typical trajectory is shown in Fig.7, the position of the pick-up in relation to the trajectory is also shown.

The results obtained for two firings of sighter rounds are given in the following tables.

Disturbance Number One

Pick-up Number	1st Pressure		2nd Pressure		
	Peak Pressure lb/sq. ft	Duration Secs.	Time After 1st Peak Secs.	Peak Pressure lb/sq. ft	Duration Secs.
1	0.36	0.004	0.564	0.04	0.009
2	0.30	0.004	0.564	0.04	0.009
3	0.37	0.044	-	-	-

Disturbance Number Two

Pick-up Number	1st Pressure		2nd Pressure		
	Peak Pressure lb/sq. ft	Duration Secs.	Time After 1st Peak Secs.	Peak Pressure lb/sq. ft	Duration Secs.
1	0.30	0.004	0.576	0.04	0.009
2	0.29	0.004	0.576	0.05	0.009
3	0.27	0.004	-	-	-

6 Discussion of Results

Correlation with theory

According to Warren's hypothesis the sonic bang is associated with the aerodynamic disturbance created along its flight path by the passage of an aircraft. The disturbance due to the motion of the aircraft can be represented by an infinite series of "source sink" pulses generated along its track by the volume of air displaced by the aircraft. These impulses are propagated as pressure waves at sonic velocity. A sonic bang occurs when the aircraft flies in such a way that the "source sink" impulses generated during a comparatively large interval of time are propagated so as to arrive simultaneously at an observer. This occurs when the aircraft is flying at supersonic speeds and its component of velocity in the direction of the observer is sonic.

It is evident from a consideration of the typical flight path shown in Fig.4 that more than one bang can be received at the same point on the ground. For example, if the aircraft is diving directly towards the observer when it first reaches M = 1 the velocity of the pulse will then be sonic in the direction of the observer. At a later stage in the flight path, for example during the commencement of pull out at say M = 1.1, it is again possible for the component of velocity in the direction of the observer, to be sonic: another bang will therefore be received by the observer and will arrive before the first bang because the aircraft's component of velocity in the observer's direction will have been supersonic in the interim.

The flight paths of the aircraft flown at Lasham were all similar and were known with reasonable certainty. On the basis of the foregoing hypothesis it was therefore possible to estimate the order of the time interval between two successive bangs, and compare it with the interval measured in cases where two bangs were observed. At Lasham this interval varied from 0.12 to 0.125 seconds, and the approximate values estimated from the theory were of the same order of magnitude.

The peak pressures estimated from theory were also in fair agreement with those measured. The aircraft experiments therefore gave a reasonable degree of quantitative substantiation for the theory, however, the timing of the bangs could equally well have been explained by the acoustic theory, according to which the bangs are associated with engine noise. The aircraft experiments were therefore not conclusive. On this point the rocket experiments at Larkhill were decisive since the first bang could only have been made when the rocket was decelerating through Mach 1 with the rocket motor inoperative, thus conclusively demonstrating that the first bang heard by the observer must have been due to an aerodynamic effect.

The agreement between the measured and calculated pressures was very good in this case, as is shown from the following comparisons:-

Pressure lb/sq. ft	Measured	Calculated
First bang	0.32	0.38
Second bang	0.04	0.05

7 Assessment of Probability of Damage to Property

It is very difficult to obtain specific threshold values of peak pressure amplitude or pressure impulse of the pressure time curve below which damage to property may not be expected to occur. This is inevitable because of the wide range of types of property involved, and the enormous degree of variation in their conditions of maintenance. The problem is further complicated by the possibility of magnification due to mechanical resonance and various other effects, such as for example the effect of age and residual strain on glass panes in window frames.

The Ministry of Works has made a study of these matters in relation to the effects of bomb blast damage to property and has deduced certain threshold criteria from data gleaned from various sources, including war damage to buildings and deliberate experiments made with known weights of explosive placed at various distances from blast pressure recording instruments.

The values deduced for the peak blast pressure and pressure impulse (the latter quantity being defined as the area under the positive portion of the pressure time curve) below which the probability of damage to property is negligibly small are as follows:-

Threshold pressure = 30 lb/ft^2

Threshold impulse = 0.05 lb sec/ft^2.

For comparison the measurements with aircraft have yielded the following figures:-

Typical peak pressure = 2 lb/ft^2

Typical impulse = 0.02 lb sec/ft^2.

It would appear therefore that the aircraft sonic bangs measured up to the present time are below the thresholds. Nevertheless, in view of the foregoing considerations the possibility of occasional damage due to freak effects cannot be ruled out.

8 Conclusions

The measurements made with aircraft and with rockets have substantiated the theory of Warren.

The magnitudes of the disturbances measured have shown that with existing aircraft the probability of extensive damage being caused to property by sonic bangs is small, although the possibility of occasional damage due to freak effects cannot be ruled out.

In the future, however, the problem may well become more serious when aircraft capable of flying level at supersonic speeds at low altitudes are developed.

REFERENCES

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2	M.O.W. Wolfe, S. Martin and J.A. Judge	Condenser type indicators for fluctuating pressures RAE Report No. SME 3371
3	G.E. Bennet, G.R. Richards and E.G. Voss	Electronics applied to measurement of physical quantities RAE Report Instn.1

Attached

Figures 1-7
Drg. Nos. SME 78128/R-78131/R inclus.
Neg. No. 122,221
Detachable Abstract Cards

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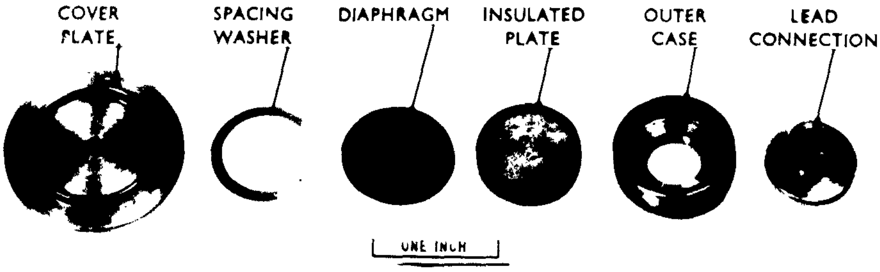

FIG. 1 EXPLODED VIEW OF CONDENSER PICK UP

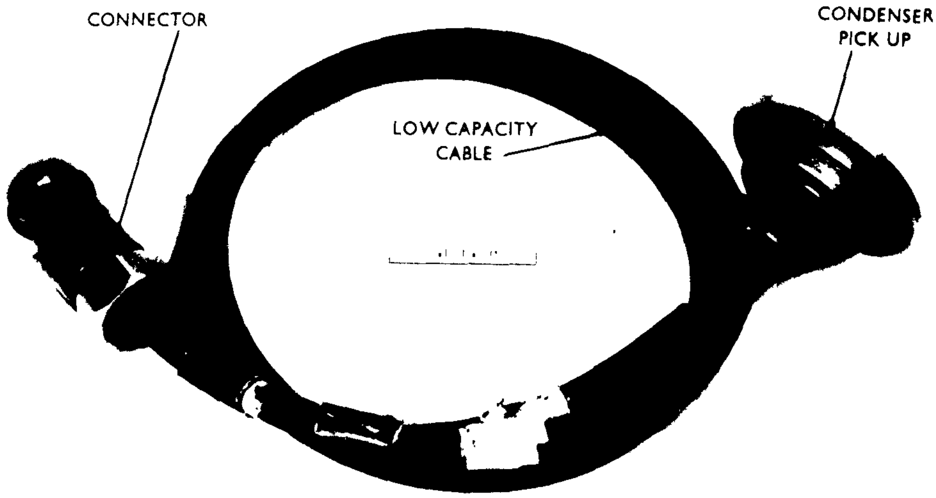

FIG 2. ASSEMBLED VIEW OF CONDENSER PICK UP

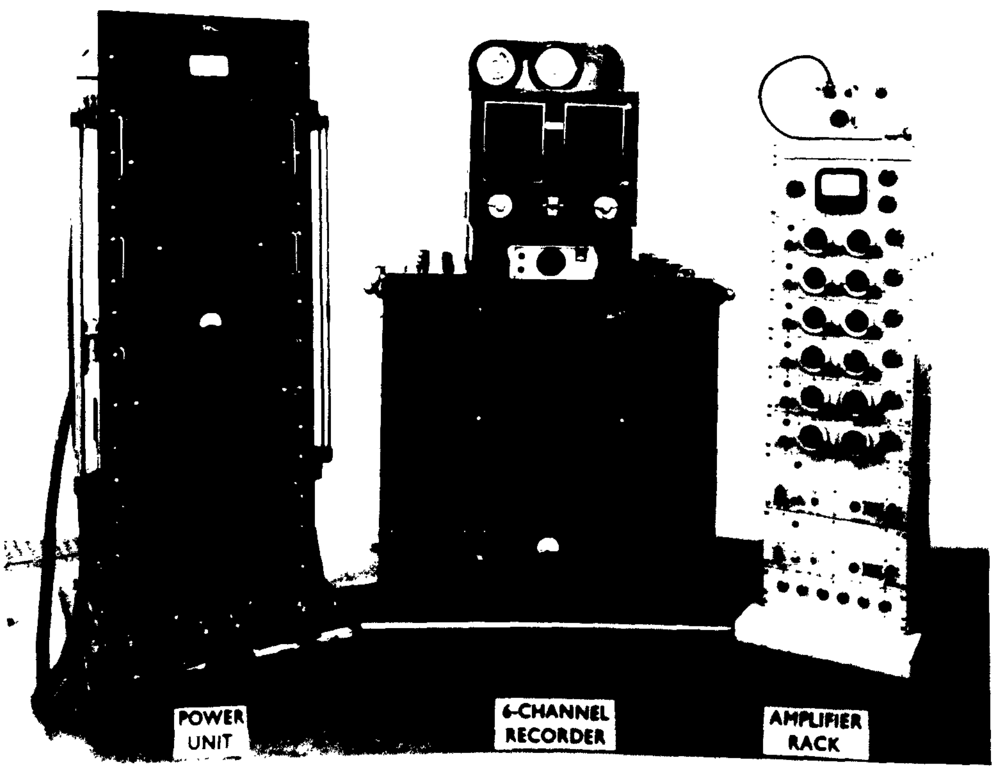

FIG 3 EQUIPMENT USED FOR MEASUREMENT OF SONIC BANGS

[redacted]

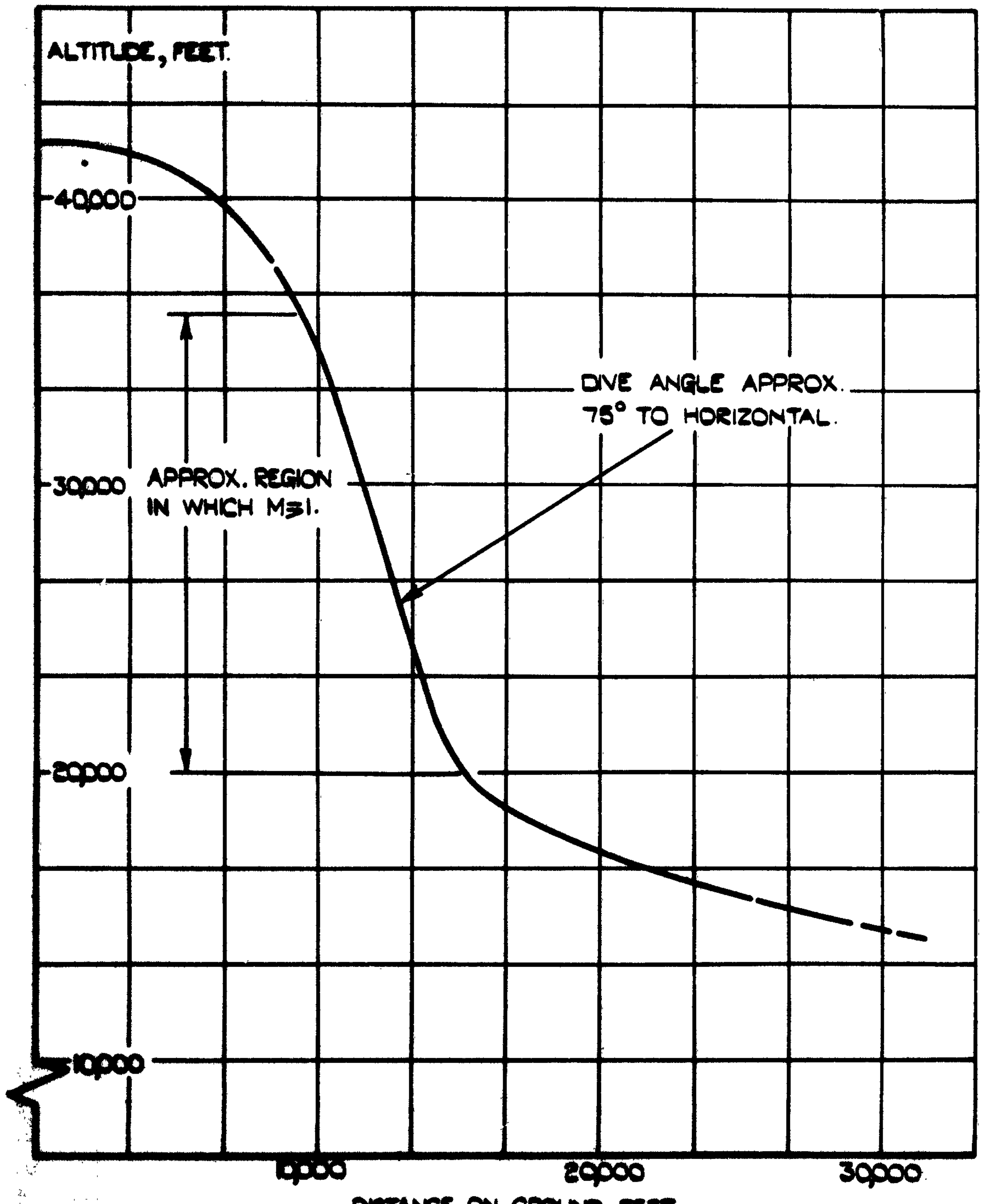

FIG. 4. APPROXIMATE FLIGHT PATH OF F.86 AIRCRAFT.

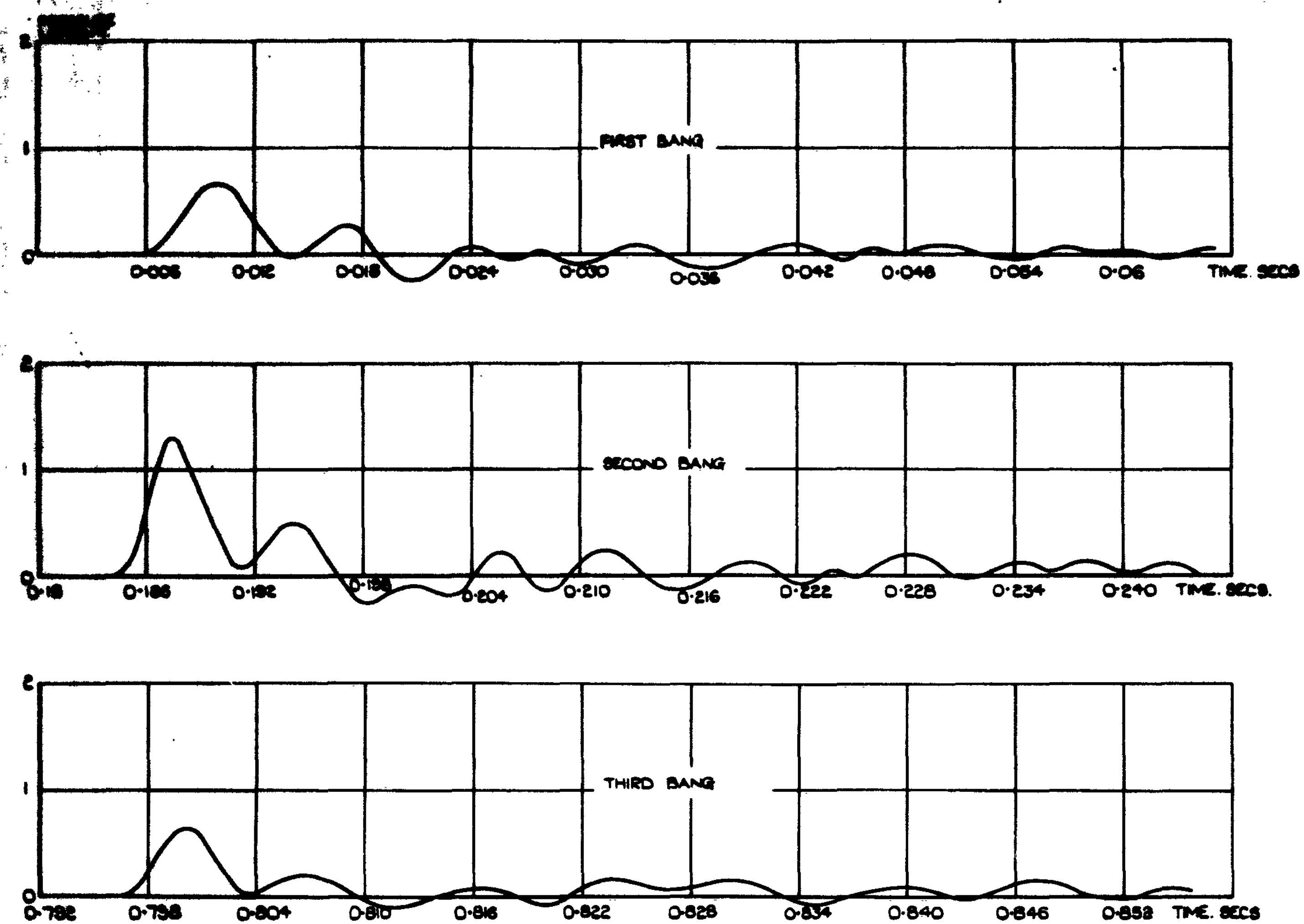

FIG. 5. ENLARGMENT OF A RECORDING OF A TYPICAL TRIPLE BANG DISTURBANCE CAUSED BY AN AIRCRAFT.

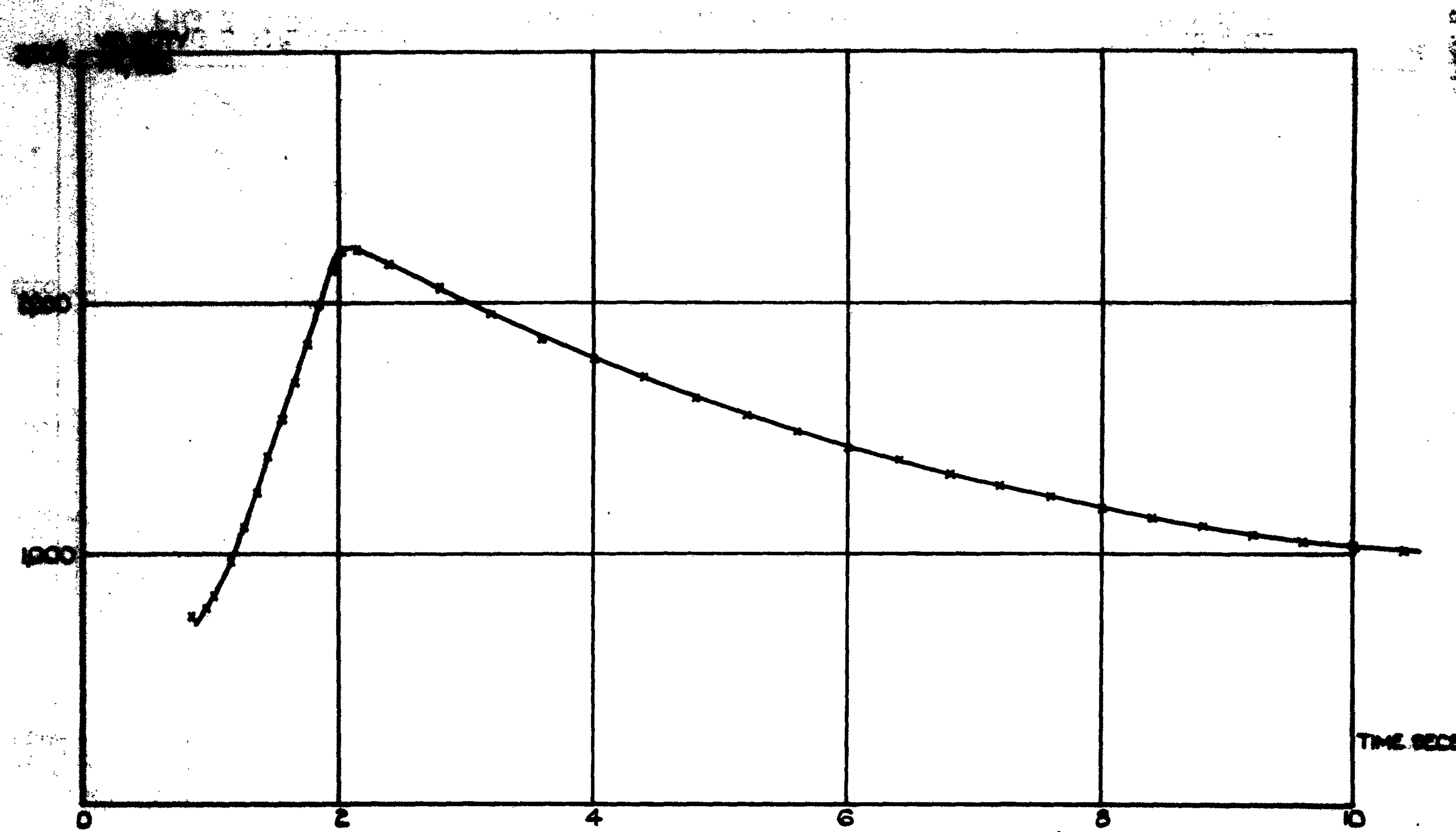

FIG. 6. VELOCITY - TIME CURVE FOR A STANDARD SIGHTER ROCKET.

REP. ... FIG. 6.

RER STRUCT. 181.
FIG. 7.

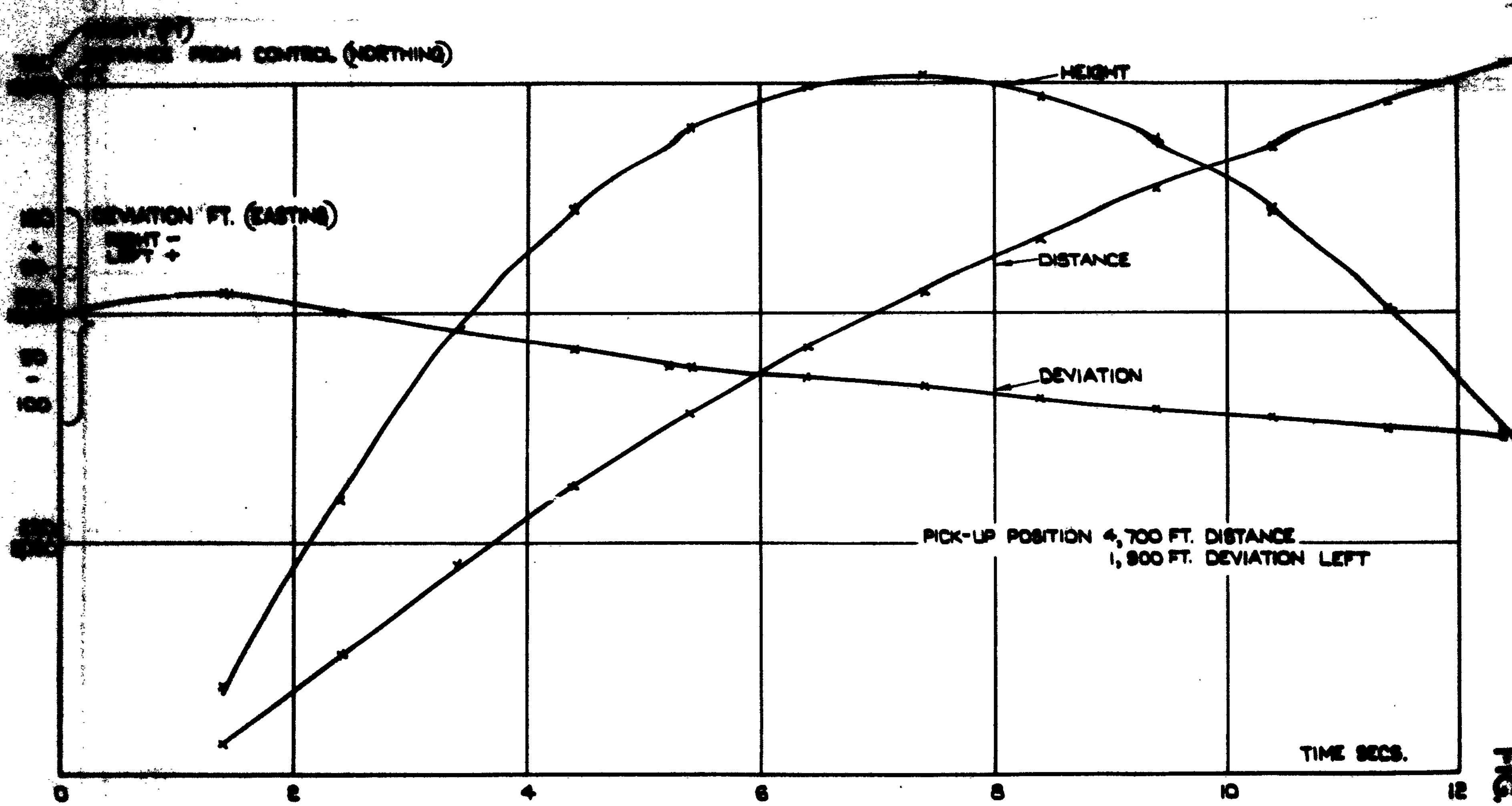

FIG. 7. TRAJECTORY CURVES FOR A STANDARD SIGHTER ROCKET.

[dstl]

Information Centre
Knowledge Services
[dstl] Porton Down,
Salisbury
Wilts
SP4 0JQ
22060-6218
Tel: 01980-613753
Fax 01980-613970

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